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REDLINE VERSION

colour inside

Hydraulic machines – Guidelines for dealing with hydro-abrasive erosion in kaplan, francis, and pelton turbines

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CONTENTS

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International Standard IEC 62364 has been prepared by IEC technical committee 4: Hydraulic turbines.

This second edition cancels and replaces the first edition published in 2013. This edition constitutes a technical revision.

This edition includes the following significant technical changes with respect to the previous edition:

a) the formula for TBO in Pelton reference model has been modified;
b) the formula for calculating sampling interval has been modified;
c) the chapter in hydro-abrasive erosion resistant coatings has been substantially modified;
d) the annex with test data for hydro-abrasive erosion resistant materials has been removed;
e) a simplified hydro-abrasive erosion evaluation has been added.

The text of this International Standard is based on the following documents:

FDIS	Report on voting
4/351/FDIS	4/366/RVD

Full information on the voting for the approval of this International Standard can be found in the report on voting indicated in the above table.

This document has been drafted in accordance with the ISO/IEC Directives, Part 2.

The committee has decided that the contents of this document will remain unchanged until the stability date indicated on the IEC website under "http://webstore.iec.ch" in the data related to the specific document. At this date, the document will be

- reconfirmed,
- withdrawn,
- replaced by a revised edition, or
- amended.

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INTRODUCTION

Many owners of hydroelectric plants contend with the sometimes very aggressive deterioration of their machines due to particle abrasion. Such owners must find the means to communicate to potential suppliers of machines for their sites, their desire to have the particular attention of the designers at the turbine design phase, directed to the minimization of the severity and effects of particle abrasion.

The number of hydro power plants with hydro-abrasive erosion is increasing worldwide.

An overall approach is needed to minimize the impact of this phenomenon. Already at the start of the planning phase an evaluation should be done to quantify the hydro-abrasive erosion and the impact on the operation. For this, the influencing parameters and their impact on the hydro-abrasive erosion have to be known. The necessary information for the evaluation comprises among others the future design, the particle parameters of the water, which will pass the turbine, the reservoir sedimentation and the power plant owner's framework for the future operation like availability or maximum allowable efficiency loss, before an overhaul needs to be done.

Based on this evaluation of the hydro-abrasive erosion, an optimised solution can then be found, by analysing all measures in relation to investments, energy production and maintenance costs as decision parameters. Often a more hydro-abrasive erosion-resistant design, instead of choosing the turbine design with the highest efficiency, will lead to higher revenue. This analysis is best performed by the overall plant designer.

With regards to the machines, owners should find the means to communicate to potential suppliers for their sites, their desire to have the particular attention of the designers at the turbine design phase, directed to the minimization of the severity and effects of hydro-abrasive erosion.

Limited consensus and very little quantitative data exists on the steps which the designer could and should take to extend the useful life before major overhaul of the turbine components when they are operated under severe particle abrasion hydro-abrasive erosion service. This has led some owners to write into their specifications, conditions which cannot be met with known methods and materials.

HYDRAULIC MACHINES – GUIDELINES FOR DEALING WITH HYDRO-ABRASIVE EROSION IN KAPLAN, FRANCIS, AND PELTON TURBINES

1 Scope

This document gives guidelines for:

a) presenting data on ~~particle abrasion~~ hydro-abrasive erosion rates on several combinations of water quality, operating conditions, component materials, and component properties collected from a variety of hydro sites;

b) developing guidelines for the methods of minimizing ~~particle abrasion~~ hydro-abrasive erosion by modifications to hydraulic design for clean water. These guidelines do not include details such as hydraulic profile shapes which ~~should be~~ are determined by the hydraulic design experts for a given site;

c) developing guidelines based on "experience data" concerning the relative resistance of materials faced with ~~particle abrasion~~ hydro-abrasive erosion problems;

d) developing guidelines concerning the maintainability of ~~abrasion resistant~~ materials with high resistance to hydro-abrasive erosion and hard ~~facing~~ coatings;

e) developing guidelines on a recommended approach, which owners could and should take to ensure that specifications communicate the need for particular attention to this aspect of hydraulic design at their sites without establishing criteria which cannot be satisfied because the means are beyond the control of the manufacturers;

f) developing guidelines concerning operation mode of the hydro turbines in water with particle materials to increase the operation life.

It is assumed in this document that the water is not chemically aggressive. Since chemical aggressiveness is dependent upon so many possible chemical compositions, and the materials of the machine, it is beyond the scope of this document to address these issues.

It is assumed in this document that cavitation is not present in the turbine. Cavitation and ~~abrasion may~~ hydro-abrasive erosion can reinforce each other so that the resulting erosion is larger than the sum of cavitation erosion plus ~~abrasion~~ hydro-abrasive erosion. The quantitative relationship of the resulting ~~abrasion~~ hydro-abrasive erosion is not known and it is beyond the scope of this document to assess it, except to ~~recommend~~ suggest that special efforts be made in the turbine design phase to minimize cavitation.

Large solids (e.g. stones, wood, ice, metal objects, etc.) traveling with the water ~~may~~ can impact turbine components and produce damage. This damage ~~may~~ can in turn increase the flow turbulence thereby accelerating wear by both cavitation and ~~abrasion~~ hydro-abrasive erosion. ~~Abrasion~~ Hydro-abrasive erosion resistant coatings can also be damaged locally by impact of large solids. It is beyond the scope of this document to address these issues.

This document focuses mainly on hydroelectric powerplant equipment. Certain portions ~~may~~ can also be applicable to other hydraulic machines.

2 Terms, definitions and symbols

For the purposes of this document, the following terms and definitions ~~and symbols~~ apply.

ISO and IEC maintain terminological databases for use in standardization at the following addresses:

- IEC Electropedia: available at http://www.electropedia.org/
- ISO Online browsing platform: available at http://www.iso.org/obp

NOTE 1 Terms and definitions are also based, where relevant, on IEC TR 61364.

NOTE 2 The International System of Units (S.I.) is adopted throughout this document but other systems are allowed.

Sub-clause	Term	Definition	Symbol	Unit
2.2.1	specific hydraulic energy of a machine	specific energy of water available between the high and low pressure reference sections 1 and 2 of the machine Note 1 to entry: For full information, see IEC 60193.	E	J/kg
2.2.2	acceleration due to gravity	local value of gravitational acceleration at the place of testing Note 1 to entry: For full information, see IEC 60193.	g	m/s²
2.2.3	turbine head pump head	available head at hydraulic machine terminal $H = E/g$	H	m
2.2.4	reference diameter	reference diameter of the hydraulic machine Note 1 to entry: For Pelton turbines this is the pitch diameter, for Kaplan turbines this is the runner chamber diameter and for Francis and Francis type pump turbines this is the blade low pressure section diameter at the band Note 2 to entry: See IEC 60193 for further information.	D	m
2.2.5	hub diameter	the diameter of runner hub for Kaplan turbines	D_h	mm
2.2.56	abrasion hydro-abrasive erosion depth	depth of metal layer that has been removed from a component due to particle abrasion material removed (measured perpendicular to the original surface) from a component due to hydro-abrasive erosion	S	mm
2.2.67	characteristic velocity	characteristic velocity defined for each machine component and used to quantify particle abrasion hydro-abrasive erosion damage Note 1 to entry: See also 2.2.20 to 2.2.24.	W	m/s
2.2.78	particle concentration	mass concentration of all solid particles per m³ of water solution particles, i.e. the mass of solid particles per volume of water-particle mixture Note 1 to entry: In case the particle concentration is expressed in parts per million (ppm) it is recommended to use the mass of particles per mass volume of water, so that 1 000 ppm approximately corresponds to 1 kg/m³.	C	kg/m³

Sub-clause	Term	Definition	Symbol	Unit
2.2.~~8~~9	particle load	~~the particle concentration integrated over the time, *T*, that is under consideration~~ the integral of the modified particle concentration over time: $$PL=\int_0^T C(t)\times K_{\text{size}}(t)\times K_{\text{shape}}(t)\times K_{\text{hardness}}(t)dt$$ $$\left(\approx\sum_{n=1}^{N} C_n\times K_{\text{size},n}\times K_{\text{shape},n}\times K_{\text{hardness},n}\times T_{s,n}\right)$$ $C(t)$ = 0 if no water is flowing through the turbine. ~~If the unit is at standstill with pressurized spiral case then $C(t)$=0 when calculating PL for runner and labyrinth seals, but $C(t)\neq 0$ when calculating PL for guide vanes and facing plates.~~ Note 1 to entry: For Francis turbines $C(t)$ = 0 when calculating PL for runner and labyrinth seals, if the unit is at standstill with pressurized spiral case, but $C(t)\neq 0$ when calculating PL for guide vanes and facing plates.	PL	kg × h/m^3
2.2.~~9~~10	size factor	factor that characterizes how the ~~abrasion~~ hydro-abrasive erosion relates to the size of the abrasive particles = median particle size dP_{50} in mm	K_{size}	
2.2.~~10~~11	shape factor	factor that characterizes how the ~~abrasion~~ hydro-abrasive erosion relates to the shape of the abrasive particles Note 1 to entry: See Annex D.	K_{shape}	
2.2.~~11~~12	hardness factor	factor that characterizes how the ~~abrasion~~ hydro-abrasive erosion relates to the hardness of the abrasive particles for 13Cr4Ni stainless steel: K_{hardness} = fraction of particles harder than Mohs 4,5. for hard coated surfaces: K_{hardness} = fraction of particles harder than Mohs 7,0.	K_{hardness}	
2.2.~~12~~13	material factor	factor that characterizes how the ~~abrasion~~ hydro-abrasive erosion relates to the material properties of the base material	K_{m}	
2.2.~~13~~14	flow coefficient	coefficient that characterizes how the ~~abrasion~~ hydro-abrasive erosion relates to the water flow around each component	K_{f}	$\frac{\text{mm}\times \text{s}^{3,4}}{\text{kg}\times \text{h}\times \text{m}^{\alpha}}$
2.2.~~14~~15	sampling interval	time interval between two water samples taken to determine the concentration of abrasive particles in the water	T_{s}	h
2.2.~~15~~16	yearly particle load	Total load (PL) for 1 year of operation, i.e. PL for T = 8 760 h calculated in accordance with 2.2.~~8~~9	PL_{year}	kg × h/m^3
~~2.2.16~~	~~maximum concentration~~	~~the maximum concentration of abrasive particles over a specified time interval~~	~~C_{max}~~	~~kg/m^3~~
2.2.17	maximum particle load	maximum value of the integrand in the PL integral during a specified time interval, i.e. the maximum value of the following expression $$PL_{\text{max}}=C(t)\times K_{\text{size}}(t)\times K_{\text{shape}}(t)\times K_{\text{hardness}}(t)$$	PL_{max}	kg/m^3

Sub-clause	Term	Definition	Symbol	Unit
2.2.~~17~~18	particle median diameter	median diameter of abrasive particles in a sample, i.e. such diameter that the particles with size smaller than the value under consideration represent 50 % of the total mass of particles in the sample	dP_{50}	mm
~~2.2.18~~	~~wear resistance index~~	~~abrasion depth or volume of a reference material (generally some version stainless steel) divided by the abrasion depth or volume of the material in question, tested under the same conditions~~	~~*WRI*~~	~~-~~
2.2.19	impingement angle	angle between the particle trajectory and the surface of the substrate		°
2.2.20	characteristic velocity in Francis guide vanes characteristic velocity in Kaplan guide vanes	flow through unit divided by the minimum flow area at the guide vane apparatus ~~estimated~~ at best efficiency point $$W_{gv} = \frac{Q}{a \times Z_0 \times B_0}$$	W_{gv}	m/s
~~2.2.21~~	~~characteristic velocity in guide vanes of Kaplan, Francis or tubular turbines~~	~~speed of the water flow at guide vane location~~ ~~$W_{gv} = 0{,}5 \times \sqrt{2 \times E}$~~	~~W_{gv}~~	~~m/s~~
2.2.~~22~~21	characteristic velocity in Pelton injector	speed of the water flow at injector location $$W_{inj} = \sqrt{2 \times E}$$	W_{inj}	m/s
2.2.~~23~~22	characteristic velocity in ~~Kaplan or Francis tubular~~ turbine runner	relative velocity between the water and the runner blade estimated with below formulas at best efficiency point $$W_{run} = \sqrt{u_2{}^2 + c_2{}^2}$$ $$u_2 = n \times \pi \times D$$ $$c_2 = \frac{Q \times 4}{\pi \times D^2} (Francis)$$ $$c_2 = \frac{Q \times 4}{\pi \times (D^2 - D_h{}^2)} (Kaplan)$$ ~~Note 1 to entry: In calculation of c_2 for Kaplan turbines, the hub diameter has been neglected in the interest of simplicity.~~	W_{run}	m/s
2.2.~~24~~23	characteristic velocity in Pelton runner	~~speed of the water flow at a Pelton runner~~ relative velocity between the water and the runner bucket $$W_{run} = 0{,}5 \times \sqrt{2 \times E}$$	W_{run}	m/s
2.2.~~25~~24	discharge ~~(volume flow rate)~~	volume of water per unit time passing through any section in the system	Q	m^3/s
2.2.~~26~~25	guide vane opening	average shortest distance between adjacent guide vanes (at a specified section if necessary) Note 1 to entry: For further information, see IEC 60193.	a	m
2.2.~~27~~26	number of guide vanes	total number of guide vanes in a turbine	z_0	

Sub-clause	Term	Definition	Symbol	Unit
2.2.2827	distributor height	height of the distributor in a turbine	B_0	m
2.2.2928	rotational speed	number of revolutions per unit time	n	1/s
2.2.3029	specific speed	commonly used specific speed to of a hydraulic machine $$n_S = \frac{60 \times n \times \sqrt{P}}{H^{5/4}}$$ P and H are taken in the rated operating point and given in kW and m respectively	n_s	rpm
2.2.3130	output	output of the turbine in the rated operating point	P	kW
2.2.3231	actual abrasion hydro-abrasive erosion depth of target unit	estimated actual depth of metal that will be removed from a component of the target turbine due to particle abrasion hydro-abrasive erosion Note 1 to entry: For use with the reference model.	$S_{target, actual}$	mm
2.2.3332	actual abrasion hydro-abrasive erosion depth of reference unit	the actual hydro-abrasive erosion depth of metal that has been removed from a component of the reference turbine due to particle abrasion hydro-abrasive erosion Note 1 to entry: For use with the reference model.	$S_{ref, actual}$	mm
2.2.3433	number of nozzles	number of nozzles in a Pelton turbine	z_0 z_{jet}	
2.2.3534	bucket width	bucket width in a Pelton runner	B_2	mm
2.2.3635	number of buckets	number of buckets in a Pelton runner	z_2	
2.2.3736	time between overhaul for target unit	time between overhaul for target unit Note 1 to entry: For use with the reference model.	TBO_{target}	h
2.2.3837	time between overhaul for reference unit	time between overhaul for reference unit Note 1 to entry: For use with the reference model.	TBO_{ref}	h
2.2.3938	turbine reference size	reference size for calculation curvature dependent effects of hydro-abrasive erosion Note 1 to entry: For Francis turbines, it is the reference diameter, D (see 2.2.4). Note 2 to entry: For Pelton turbines it is the inner bucket width, B_2. Note 3 to entry: For further information in the inner bucket width, B_2, see IEC 60609-2.	RS	m
2.2.4039	size exponent	exponent that describes the size dependant effects of hydro-abrasive erosion in evaluating RS	p	
2.2.4140	exponent	numerical value of 0,4-p that balances units for K_f	α	

3 Abrasion rate Prediction of hydro-abrasive erosion rate

3.1 Model for hydro-abrasive erosion depth

The following formula can be used to estimate the hydro-abrasive erosion depth in a Francis turbine: